Ghost Imaging of Space Objects

Completed Technology Project (2011 - 2012)

Project Introduction

Ghost imaging is an optical imaging technique that utilizes the correlations between optical fields in two channels. One of the channels contains the object, however lacks any spatial resolution. In the other, empty channel a space-resolving optical detection is allowed. The image is reconstructed by correlating the signals from two channels. In the original implementation, the channels had to be coupled to quantum-correlated (entangled) optical fields. Later it was shown that this approach could also work with ordinary thermal light (e.g., star light), which also possesses correlation properties. However the ghost imaging geometry remains poorly compatible with the imaging of astronomical objects. Specifically, creating the correlated optical channels requires a beam splitter to be placed between the source and the object. The study team recently re-examined this requirement and found a possibility to avoid it, therefore potentially opening the doors to the ghost-imaging of distant objects using natural light. The key to the proposed approach is the understanding that an optical mode can be coupled in two channels not only by splitting its amplitude with a beam splitter, but also by sub-mode detection, which occurs naturally when the object is smaller than the transverse coherence length. In Phase-I the team will discuss the requirements arising for this type of ghost imaging and theoretically validate the novel approach.

Anticipated Benefits

Potential benefits of the application of ghost imaging in astronomy and astrophysics include the enhanced resolution and broader range imaging of extra-terrestrial objects, such as Earth-like planets (including those near bright stars), black holes, and dust or gas clouds. Optical imaging in astronomy will remain an active area of NASA's deep space exploration efforts for many years to come, and developing a novel architecture geared to provide new or enhanced data will definitely have a high impact. Practical applications of conventional and computational ghost imaging is an active area of research in the engineering community, including JPL (stand-off sensing instruments for DARPA). This interest is justified the reduced optical and photodetector complexities inherent in ghost imaging. However, a thorough feasibility study is required prior to launching a large-scale effort focused on astronomy and astrophysics applications. We propose to carry out such a study and present our recommendations by the Phase II start, as to whether such an effort would be practical at the present level of technology.

Project Image Ghost Imaging of Space Objects

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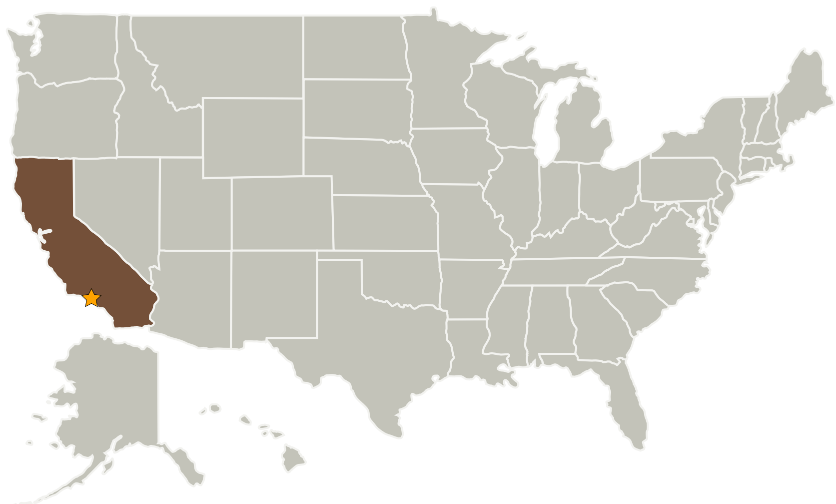
Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★Jet Propulsion Laboratory(JPL)	Lead Organization	NASA Center	Pasadena, California
Max Planck Institute for the Science of Light	Supporting Organization	Industry	Erlangen, Outside the United States, Germany

Primary U.S. Work Locations
California

Project Transitions

September 2011: Project Start

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Center / Facility:

Jet Propulsion Laboratory (JPL)

Responsible Program:

NASA Innovative Advanced Concepts

Project Management

Program Director:

Jason E Derleth

Program Manager:

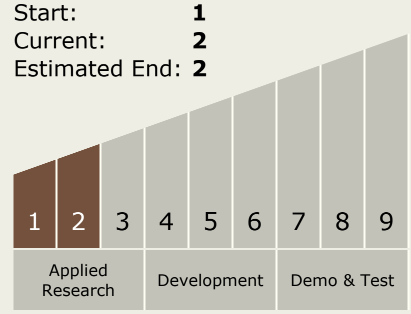
Eric A Eberly

Principal Investigator:

Dmitry V Strekalov

Technology Maturity (TRL)

Start: **1**
Current: **2**
Estimated End: **2**



September 2012: Closed out

Closeout Summary: During our Phase I NIAC research eort we have investigated the possibility of performing intensity correlation\\ghost imaging" of dark amplitude and phase objects in space illuminated by thermal light sources (stars). Our approach hinges on replacing the beam splitter, indispensable for thermal light ghost imaging but infeasible for space imaging, with the object itself. The absorptive and refractive properties of the object are predicted to imprint themselves on the intensity correlation properties of the transmitted and scattered light and could be extracted from the correlation measurements. To test this concept we limited our discussion to fully analytical model relying on a two-dimensional source and an object with Gaussian distribution of luminosity, absorption or phase delay (the latter representing a thin lens) in paraxial approximation. We demonstrated the variation of the far-field speckle size due to the presence of the object. We have shown that the speckle size variation is a non-trivial function of the object's properties and position. In some cases it allows us to distinguish dierent phase and amplitude objects even when they produce very similar shadows and can hardly be distinguished by a direct intensity measurement. Thus the correlation measurement provides a complimentary information to a direct observation. This understanding has encouraged us to apply our analytical model to a realistic space object imaging scenario, such as the Kepler mission. Our prediction for the flux variation very close to the actual observation. It also predicted a similar (about 10\xa14) fractional variation of the speckle size. We have carried out a preliminary SNR analysis for a correlation measurement, comparing it to a direct °ux measurement. The analysis has shown that, for parameters typical of the Kepler mission, the correlation measurement SNR would be signi\xafcantly worse than the intensity measurement SNR. This analysis however does not include certain instrumental types of noise, that may be detrimental for the intensity measurement more than for the correlation measurement and could potentially balance or even reverse the SNRs inequality. These are the dark noise and variation of detector's responsivity (quantum effciency) due to environmental °uctuations and aging. The ambient background light is another important factor that needs to be considered. We plan to include these factors in the advanced noise model which will be developed in the follow-on research.

Technology Areas

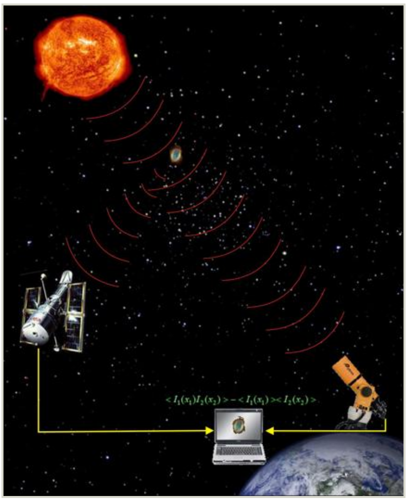
Primary:

- TX05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems
  - └ TX05.1 Optical Communications
    - └ TX05.1.5 Atmospheric Mitigation

Target Destinations

Earth, Foundational Knowledge

Images



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Project Image Ghost Imaging of Space Objects
(https://techport.nasa.gov/image/102267)